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On the Possible Existence of an East-West, F-Layer, Electron-Density Trough Extending Across the United States

by

J. C. Taenzer and G. H. Barry

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Technical Report No. 138

Prepared under
Office of Naval Research Contract
Nonr-225(64), NR 088 019, and
Advanced Research Projects Agency ARPA Order 196-67

RADIOSCIENCE LABORATORY

STANFORD ELECTRONICS LABORATORIES

STANFORD UNIVERSITY · STANFORD, CALIFORNIA

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ON THE POSSIBLE EXISTENCE OF AN EAST-WEST, F-LAYER, ELECTRON-DENSITY TROUGH EXTENDING ACROSS THE UNITED STATES

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ABSTRACT

It has been suggested that recent satellite topside sounding data seems to show a trough or localized minimum of electron density lying latitudinally across the United States. The characteristics and implications of such an F-layer anomaly have been investigated by surveying and analyzing available topside and bottomside sounding information. A trough does appear in some of the data, and it appears to have diurnal, yearly, and sunspot cycle variations. However, even during these apparent periods of highest probability of occurrence, it is not observed in any of the surveyed single-pass data, but rather only in the average of many observations (where it still is not reliably seen). Thus the conclusion was reached that, although the existence of such an anomaly in F-layer electron density would have an effect on HF point-to-point communications MUFs, nevertheless, owing to its infrequent occurrence and little understood nature, the possible existence of the anomaly should not be used as a design consideration in the layout of actual or proposed HF communications circuits across the U.S.

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I. INTRODUCTION

It has been suggested [Ref. 1] that recent satellite topside sounding data seems to show a minimum in F-layer electron density lying across the United States in an east-west direction. Such a "crinkle" anomaly would have important implications on east-west HF radio propagation across the U.S. The maximum usable frequencies (MUFs) from, say, Boston to Seattle and from Miami to Los Angeles might greatly exceed those from, say, Washington to San Francisco. Further, east-west radio paths lying along the edges of such a crinkle might show azimuthal deviations out of the great circle path. At the request of ARPA, a short study was undertaken to survey available evidence bearing on the possible existence of such an anomaly.

While the ionospheric electron density in the E-layer varies geographically in a smooth and predictable manner (being a function primarily of the solar zenith angle and the sunspot number), the F-layer electron density is notoriously variable. This difference is a result of the earth's magnetic field which, above 140 km, becomes more important than the neutral atmospheric pressure in determining the motions of ionized constituents. Irregularities in the earth's dipole field and the misalignment of the dipole field axis with the earth's rotational axis produce an astonishingly complex geographical variation in F-layer electron density. A variety of polar and equatorial anomalies have long been recognized and are more or less well understood. Recently, with the aid of topside soundings, a recurrent ionospheric crinkle was identified by Muldrew [Ref. 2] as lying at the southern edge of the northern auroral zone and apparently associated with a latitudinal gradient in the earth's magnetic field [Ref. 3]. As additional topside sounding data accumulates, further systematic localized anomalies will undoubtedly be identified. The apparent crinkle, to which this study addresses itself, is such a feature.

II. EVIDENCE FOR OR AGAINST THE EXISTENCE OF THE TROUGH

A. GENERAL DISCUSSION

An east-west crinkle in F-layer electron density crossing the United States might be observed in a variety of ways. The most straightforward of these would be to examine data from a north-south chain of vertical-incidence sounders. Alternatively, data from a number of oblique-incidence sounders operating over east-west paths could be used provided the direction of these paths was sufficiently well aligned with the suspected direction of the crinkle. Data from operational east-west communications circuits could conceivably be used to obtain the same information as that from the sounders. However, communications circuits are traditionally scheduled conservatively in frequency so that they generally provide little information on the maximum observed frequency (MOF).

Since it is desired that the end result of this study take the form of conclusions regarding the suspected crinkle's effect on east-west radio circuits across the United States, it would appear that data from oblique sounders could provide this information more directly and with greater accuracy than it could be inferred from vertical-incidence sounder measurements. Unfortunately, to be of much use, data from several simultaneously operated east-west sounder circuits is required and, while the authors are aware of a number of trans-U.S. sounder experiments, both past and present, we are unaware of any which provide enough simultaneously parallel-path data to detect or disprove the suspected crinkle. Accordingly, only data from vertical-incidence sounders will be considered.

A map showing the geographical distribution of ionosondes is shown in Fig. 1 (from data in Refs. 4 and 5). It is upon data from these sounders that the computer programs to produce ITSA world maps of vertical-incidence critical frequency are based. One might expect that if the crinkle exists it should be directly observable on these world contour maps. Examination of a number of these maps for various times of day and seasons (see examples in Fig. 2 and Ref. 6) has convinced the authors that the crinkle is not detectable in this way. This does not prove the crinkle does not exist. Muldrew's trough is likewise invisible on the world map contours, though

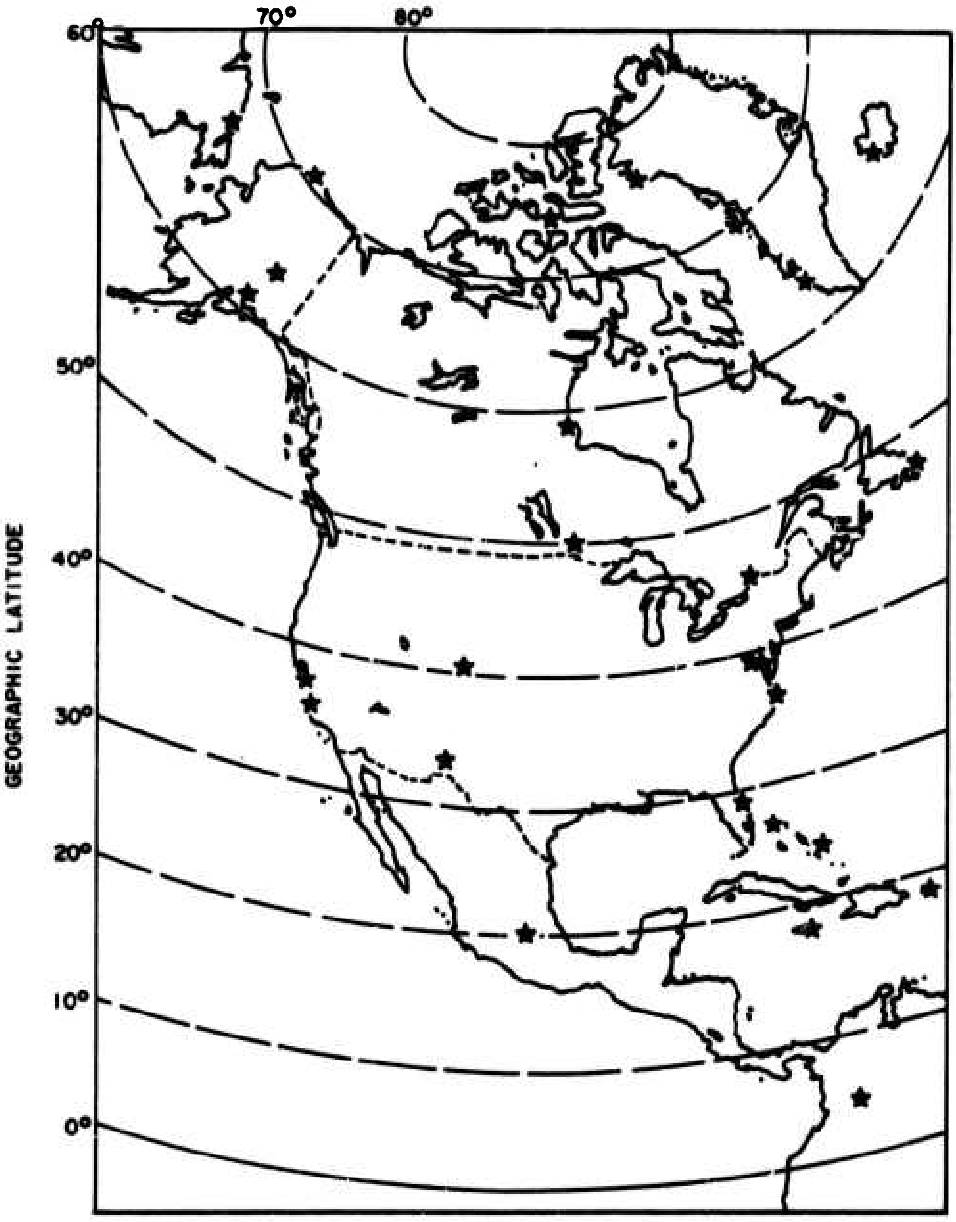
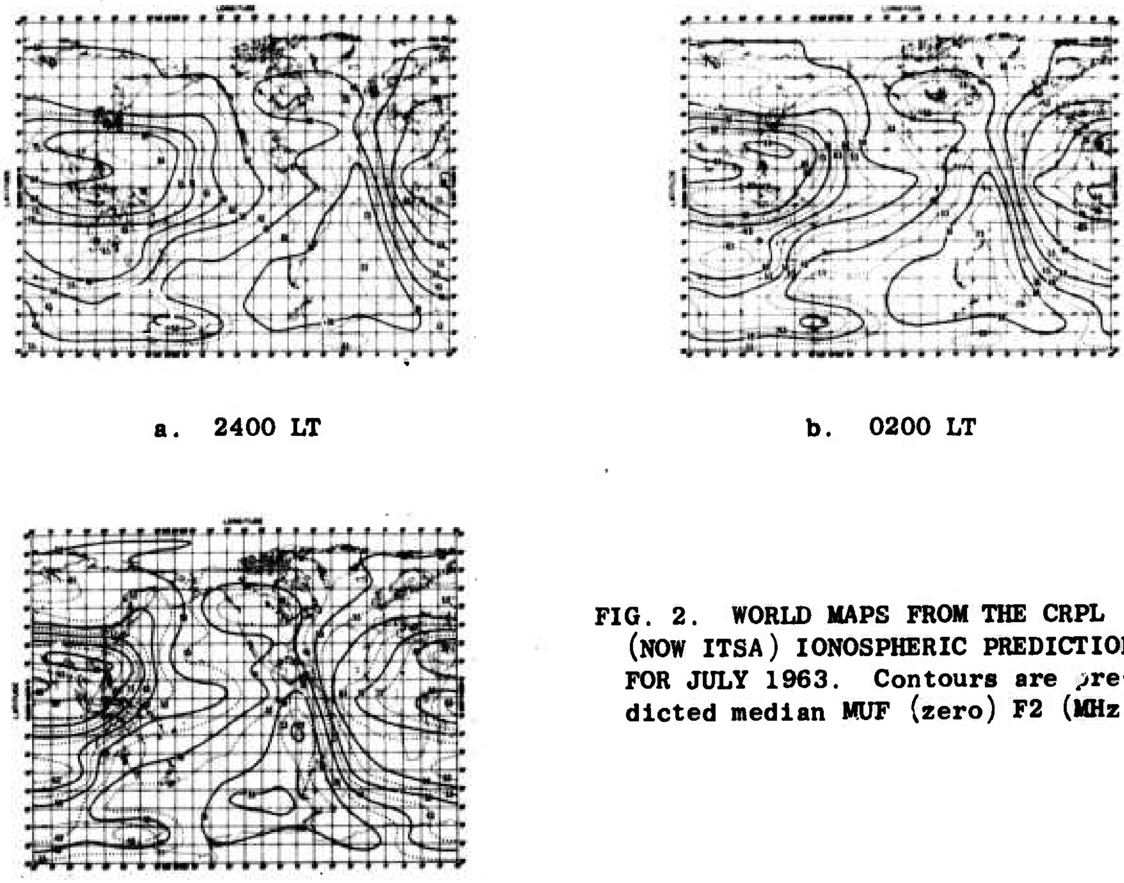


FIG. 1. IONOSPHERIC VERTICAL SOUNDING STATIONS IN THE NORTH AMERICAN AREA.

the local minimum in layer critical frequency is clearly apparent from topside soundings and must be equally detectable from below. The problem, of course, is that of inadequate data. It is readily apparent from Fig. 1 that the locations of vertical ionosondes are spaced too widely to provide information on a latitudinally narrow crinkle such as we are considering here.



a. 2400 LT

b. 0200 LT

c. 0400 LT

FIG. 2. WORLD MAPS FROM THE CRPL (NOW ITSA) IONOSPHERIC PREDICTIONS FOR JULY 1963. Contours are predicted median MUF (zero) F2 (MHz).

However, topside vertical-incidence sounder data is available [Refs. 7, 8, and 9] in the form of electron densities and plasma scale heights at various heights and times as computed from the Alouette I satellite topside sounder ionograms. The locations and geographical coverages of Alouette I telemetry stations are such that satellite ionograms taken over any part of the North American Continent could be received. Such ionograms, taken every 18 sec or 120 km (approximately every 1° of latitude) along the satellite orbit, provide much better spatial (latitudinal) resolution than that available from ground-based sounders. Thus, detailed structure of the ionosphere not observed on contour maps or in data obtained from bottomside sounders can be investigated by use of the Alouette I data.

Already Alouette data have been used to show that the low-latitude ionosphere is strongly dependent on the earth's magnetic field [Refs. 10, 11, and 12]. They have also been used to show that the mid- and upper-latitude ionosphere is also strongly dependent on the earth's magnetic field [Ref. 2] and that one of the most interesting characteristics observed at these latitudes are well-defined minimums of f_xF_2 which are approximately aligned in the magnetic east-west direction.

It is such a trough or crinkle, but at lower latitudes, which shows up in the averaged data of Fig. 3* (from data in Ref. 7). This figure shows a well-defined minimum of electron density at a dip latitude of 57.5° north. The minimum appears to have an electron density about one-fourth that observed at greater or lesser latitudes, which corresponds to a vertical- or oblique-incidence critical frequency of one-half that at other latitudes.

In comparing Fig. 3 with other figures in this report, the relationship between dip latitude and geographic latitude needs to be known. Figure 4 shows this relationship for the North American Continent. As a general rule of thumb, geographic latitudes about 40° north, corresponding to dip latitudes about 50° - 55° north, are the latitudes where the electron density minimum is suspected to occur.

Further analysis of the data in Ref. 7 seemed to indicate that the minimum shown in Fig. 3 occurs during the summer months and only at night. To help substantiate these conclusions, the data presented in Refs. 8 and 9 were scanned for appropriate single passes of the Alouette satellite, covering the latitudes of interest, between 2200 local time and 0700 local time and between 60° west and 120° west longitude. Figures 5 and 6 show two such passes. Figure 5 was the best indication of any sort of a crinkle at the desired latitude, with a slight minimum in electron density occurring at about 42° north geographic latitude. However, the minimum is so small that for any practical purpose it is negligible. Figure 6 does not show any minimum at a similar latitude but does show Muldrew's trough at about 53° north geographic latitude. Thus, data in Refs. 8

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*Figures 3 through 12 appear at the end of this chapter.

and 9 could not substantiate the suspected crinkle anomaly in F-layer electron density lying across the United States.

In order to determine what, if any, variation such a minimum of electron density might have with sunspot number, the plots in Ref. 13 were used to find values of monthly median f_oF_2 which are plotted in Fig. 7 as a function of dip latitude. The stations which supplied data for Ref. 13 and which are summarized in Table 1 do not lie at a constant longitude or even along any great circle, although they are all on the North American Continent. The data in Fig. 7 were all taken at 0300 local time at each station and are averaged values for the month of June. Data for three years is shown and these three years correspond to the minimum of sunspot activity and the two years following as can be seen in Fig. 8. The corresponding sunspot numbers are summarized in Table 2. Also shown

TABLE 1. IONOSPHERIC VERTICAL SOUNDING STATIONS WHICH FURNISHED THE DATA PLOTTED IN FIG. 7

Station	Coordinates		
	Dip Latitude (deg N)	Geographic Latitude (deg N)	Geographic Longitude (deg W)
Godhavn, Greenland	80	69.2	53.5
Narsarssuak, Greenland	71	61.2	45.4
Reykjavik, Iceland	70	64.1	21.8
Barrow, Alaska	68	71.3	156.8
College, Alaska	64	64.9	147.8
Anchorage, Alaska	61	61.2	149.9
Ft. Monmouth, New Jersey	51	40.3	74.1
Ft. Belvoir, Virginia (Washington, D.C.)	50	38.7	77.1
Adak, Alaska	48	51.9	176.6
San Francisco, California	44	37.4	122.2
White Sands, New Mexico	41	32.3	106.5
Puerto Rico, West Indies	29	18.5	67.2
Maui, Hawaii	21	20.8	156.5
Panama Canal	20	9.4	79.9

TABLE 2. SUNSPOT NUMBERS

Month and Year		Sunspot Number
June	1954	3
June	1955	32
June	1956	136
March	1963	29
May	1963	28
July	1963	28

in Table 2 are the sunspot numbers corresponding to the data in other figures in this report.

By comparing Fig. 7 with the sunspot numbers in Table 2, it appears that the tendency toward a latitudinal minimum in electron density or in critical frequency becomes less as the sunspot activity increases. As can be seen in Table 1, however, there were no stations between 51° north and 61° north dip latitude, and thus the curves in Fig. 7 show only qualitative information between these two latitudes. It is interesting to note, however, that somewhere between June 1954 and June 1955, when the sunspot number was about the same as it was during the period of time when the data for Fig. 3 (sunspot number 28) were taken, the minimum of critical frequency (Fig. 7) was very close to one-half the critical frequency at higher or lower latitudes. This agrees with the result of Fig. 3. Thus it would seem that the sunspot number may be related to the existence and to the depth of the minimum.

It is wise to keep in mind that the results expressed above are really time dependent and that the data in Fig. 3 were taken at 2400 local time, while those in Fig. 7 were taken at 0300 local time. A plot similar to Fig. 7 but at 2400 local time (Fig. 9, from data in Ref. 13) shows no minimum of electron density at a similar latitude, and yet a plot similar to Fig. 3 but at 0300 local time (Fig. 10 from data in Ref. 7) shows a minimum quite similar to that in Fig. 3. In fact, the NBS data [Ref. 13] only show the minimum between 0100 and 0500 local time

in the summer of 1954 and for even shorter intervals in the summers of 1955 and 1956. The data for the summer of 1963 (sunspot number corresponding to summer 1955) from Ref. 7 indicate a minimum for a similar period of time, but beginning earlier around 2300 local time. This diurnal variation is shown in Fig. 11. Thus, it appears that, if such a crinkle anomaly exists, it is detectable only during the early hours of the day.

From a study of the available information, it appeared that there was also a yearly variation in the cases that did show the crinkle. The NBS data [Ref. 13] were plotted to show this variation (Fig. 12). Again, because of the lack of data between 51° and 61° north latitude, the actual latitude of the minimum of f_oF_2 is not clear, but by scanning the graphs of Fig. 12, it is readily apparent that the crinkle is most noticeable during the summer months, nearly disappearing in the winter. Thus the effects of the anomaly would be noticed mainly in the summer months.

It should be pointed out that most of the figures in this report show the best data for such a minimum of electron density. However, much of the available data (for example, the world maps of Ref. 6 and the Alouette data in Refs. 8 and 9) shows no evidence of the crinkle.

B. SUMMARY OF PROBABLE CHARACTERISTICS AND BEHAVIOR

On the basis of the evidence discussed above, the probable characteristics and behavior of the F-layer electron-density trough can be summarized as follows:

(1) Width: The width of the minimum in F-layer electron density appears to be about 10° latitude.

(2) Position: The trough appears to be centered about 55° north dip latitude.

(3) Intensity: The intensity varies with time of day, sunspot number, and time of year, reaching a minimum of about one-fourth the electron density observed at higher or lower latitudes.

(4) Diurnal variation: The minimum appears during the hours of 2300 to 0500 local time.

(5) Annual variation: Effects of the minimum seem to be greatest during the summer months and smallest in the winter.

(6) Sunspot number: Periods of low sunspot number appear to coincide with periods when the minimum of electron density is deepest.

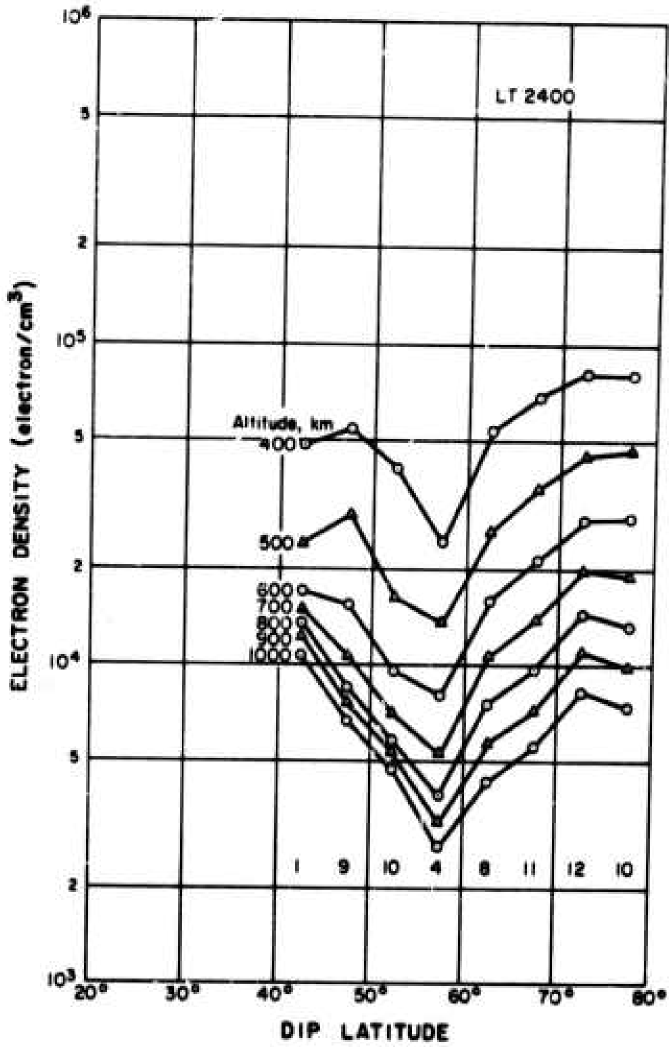


FIG. 3. ELECTRON DENSITY FOR THE SUMMER OF 1963, LOCAL TIME 2400. The numbers under the data points on the plot are the number of measurements averaged for each point.

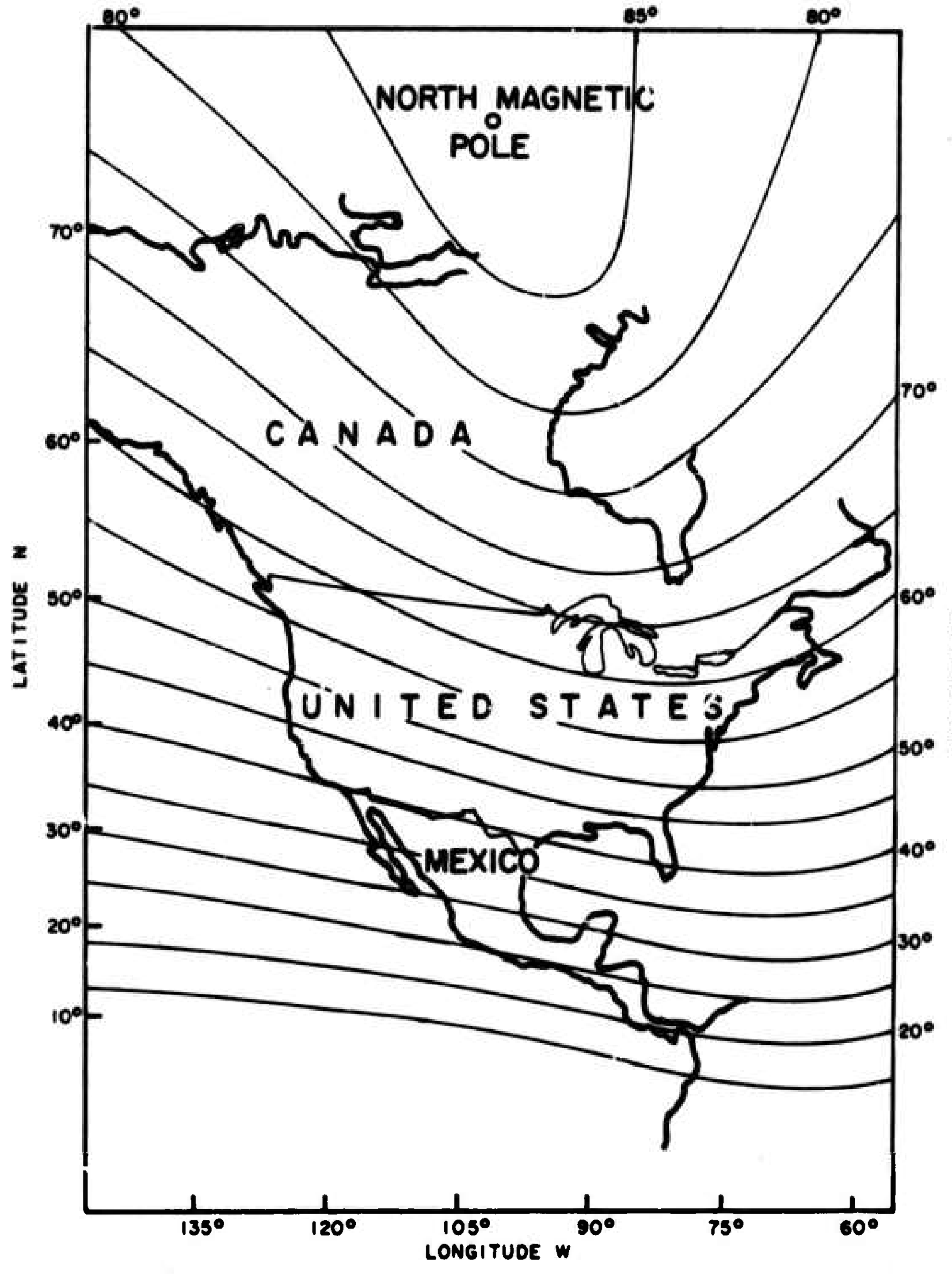


FIG. 4. DIP LATITUDES ACROSS THE NORTH AMERICAN CONTINENT.

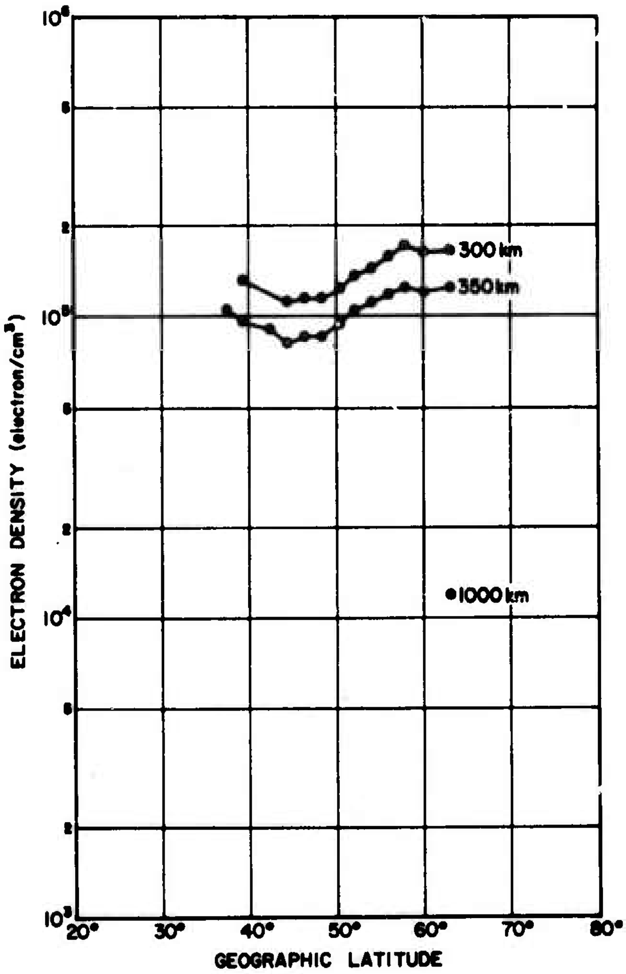


FIG. 5. ELECTRON DENSITY FOR ALOUETTE SATELLITE PASS NUMBER 3019 IN MAY 1963.

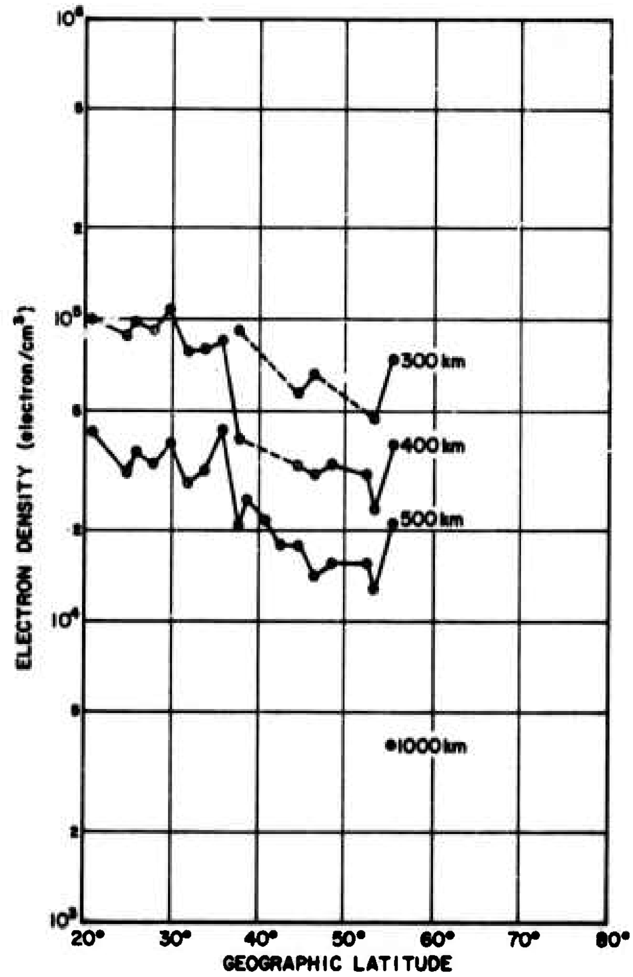


FIG. 6. ELECTRON DENSITY FOR ALOUETTE SATELLITE PASS NUMBER 2401 IN MARCH 1963.

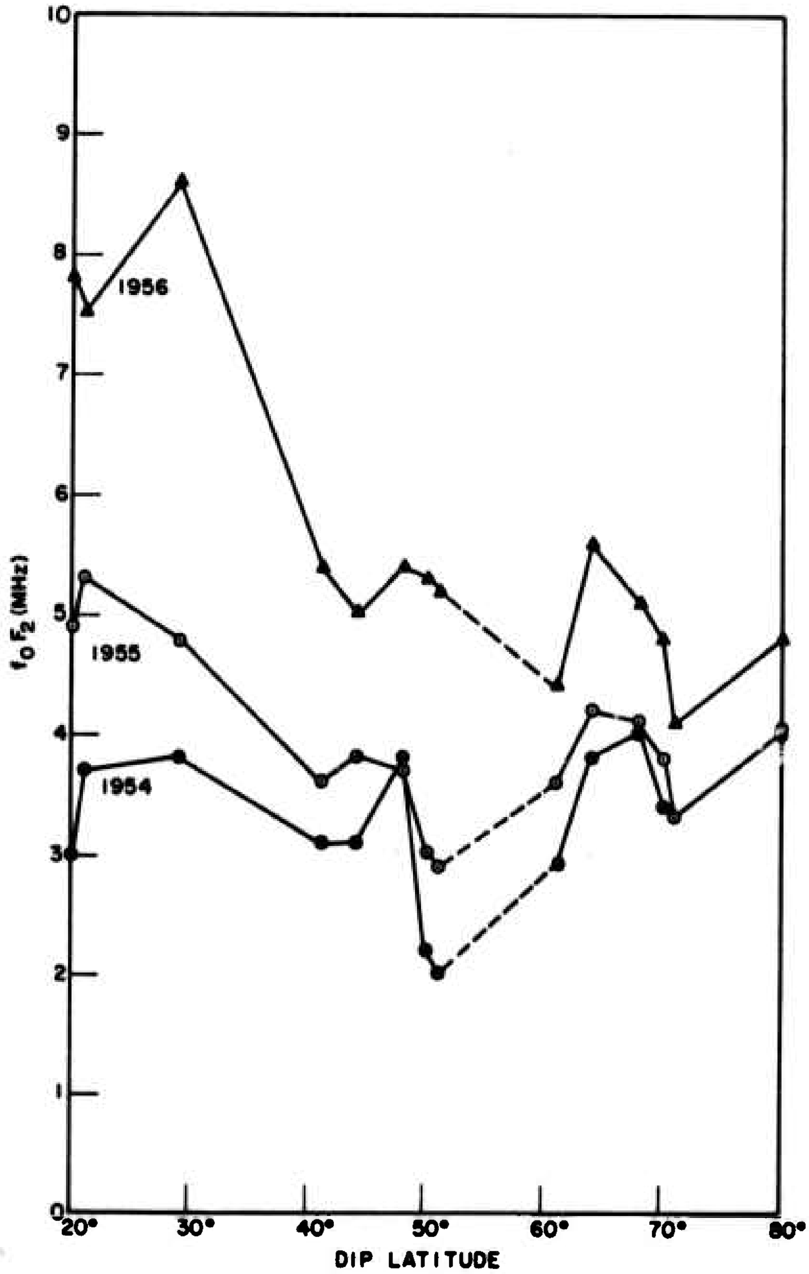


FIG. 7. MONTHLY MEDIAN f_oF_2 FOR THE MONTH OF JUNE, 0300 LOCAL TIME.

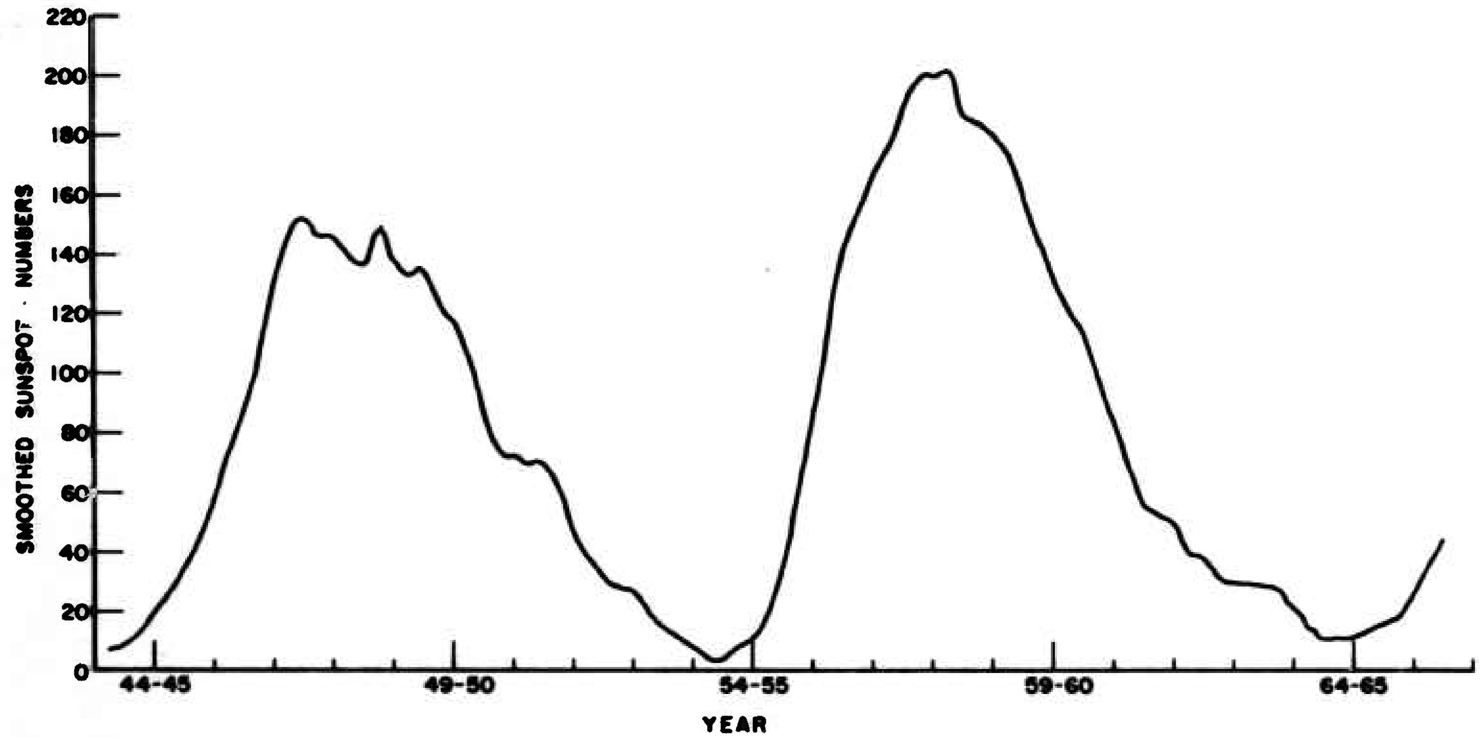


FIG. 8. SUNSPOT NUMBERS OVER THE LAST TWO SUNSPOT CYCLES.

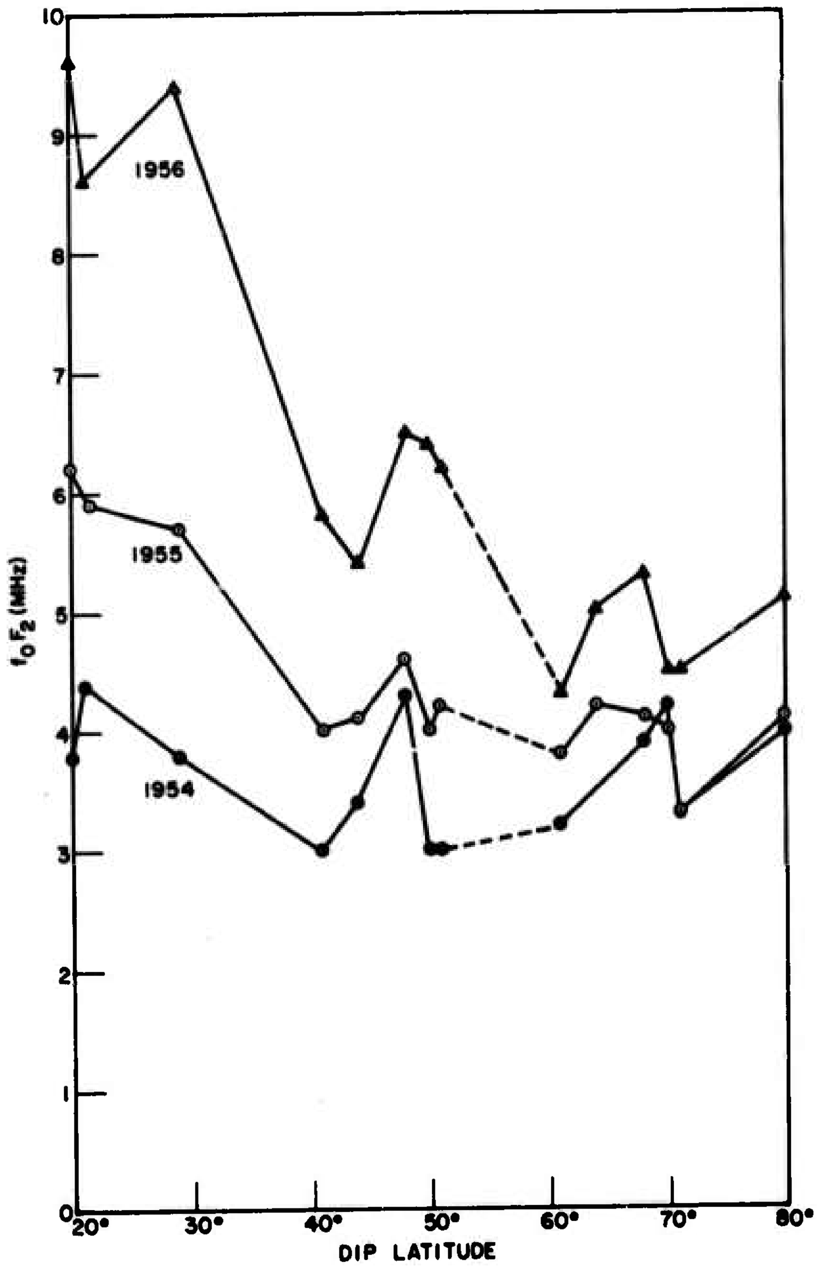


FIG. 9. MONTHLY MEDIAN f_oF_2 FOR THE MONTH OF JUNE, 2400 LOCAL TIME.

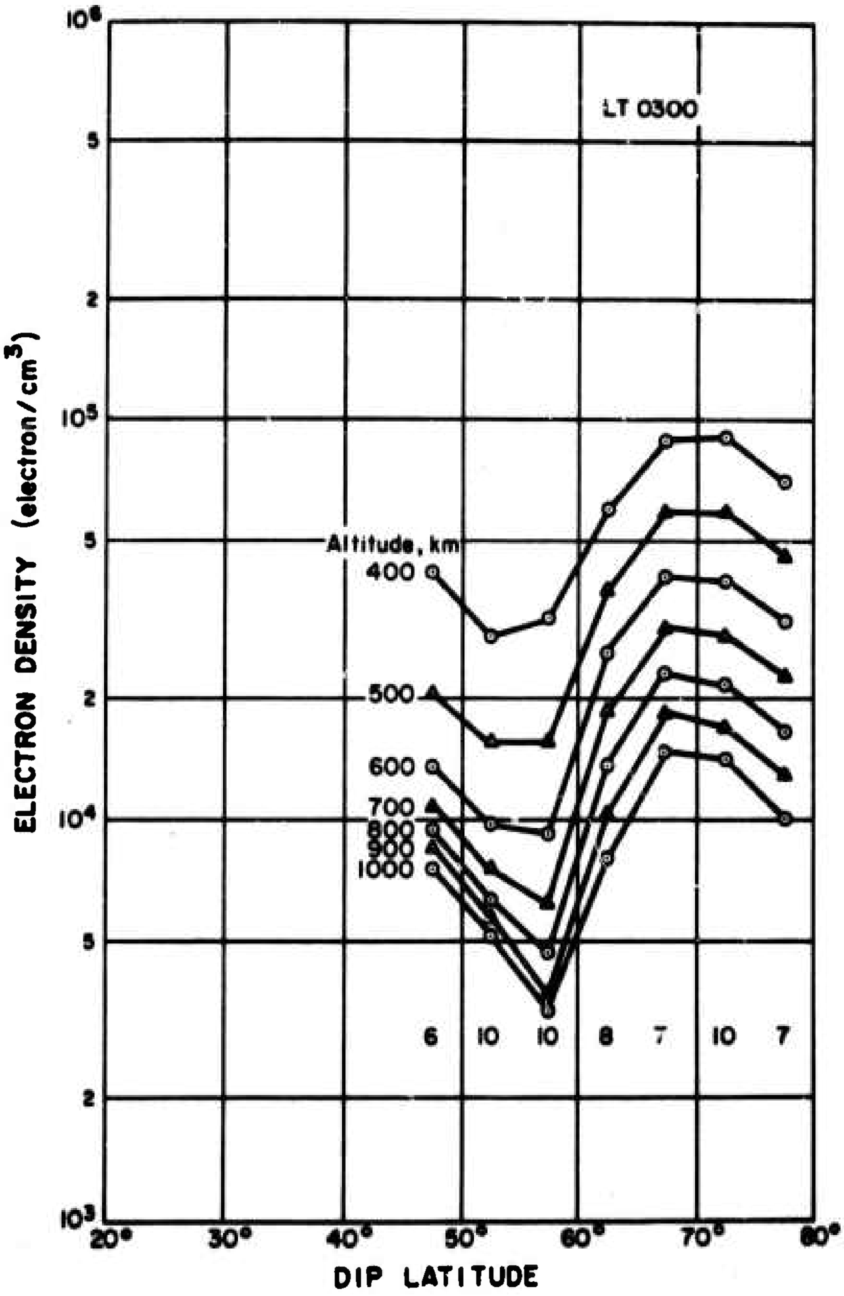
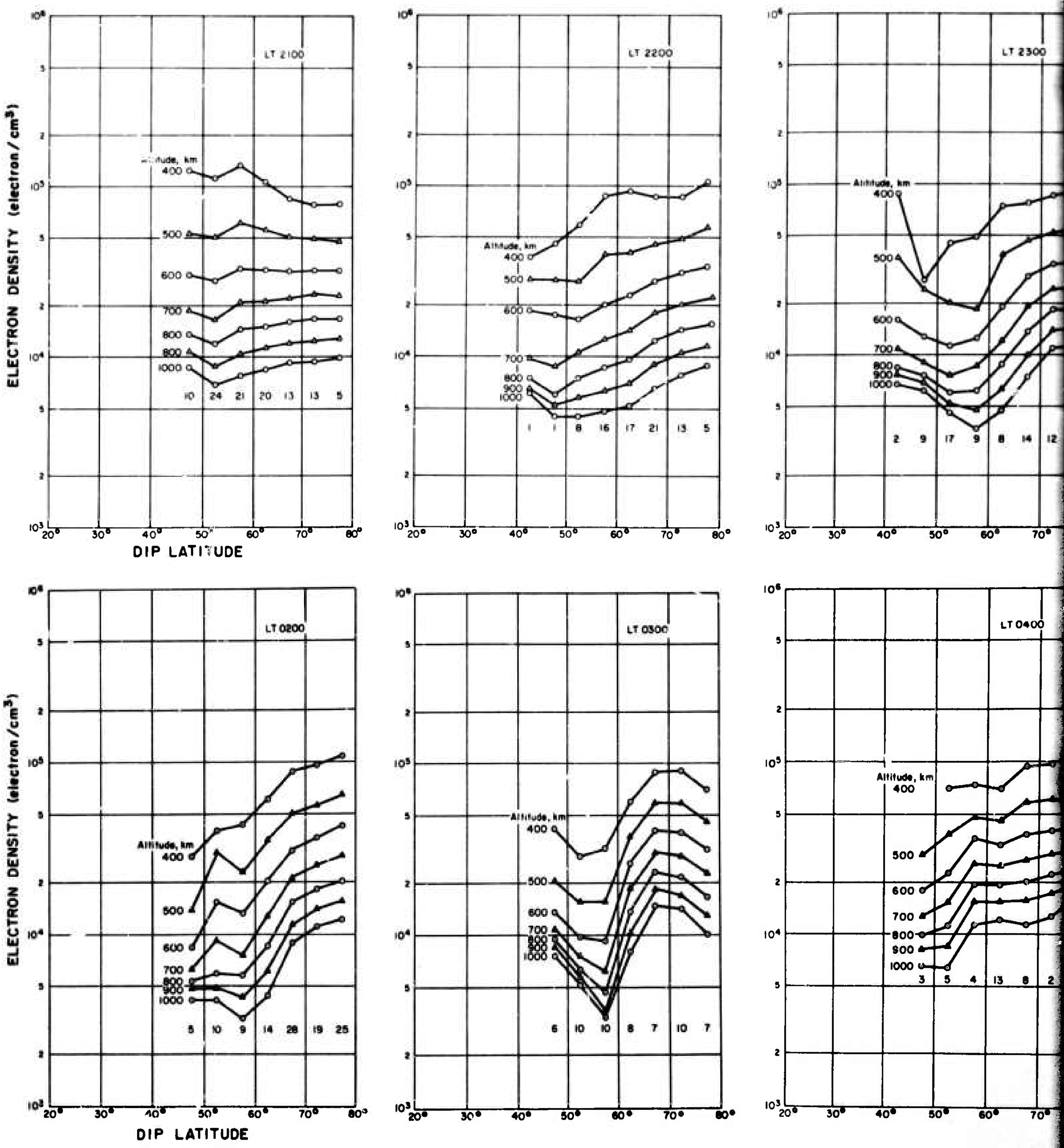


FIG. 10. ELECTRON DENSITY FOR THE SUMMER OF 1963, LOCAL TIME 0300. The numbers under the data points on the plot are the number of measurements averaged for each point.



LT 2100
LT 2200
LT 2300
LT 0200
LT 0300
LT 0400
Altitude, km
400
500
600
700
800
900
1000
ELECTRON DENSITY (electron/cm³)
DIP LATITUDE
10 24 21 20 13 13 5
1 1 8 16 17 21 13 5
2 9 17 9 8 14 12
5 10 9 14 28 19 25
6 10 10 8 7 10 7
3 5 4 13 8 2

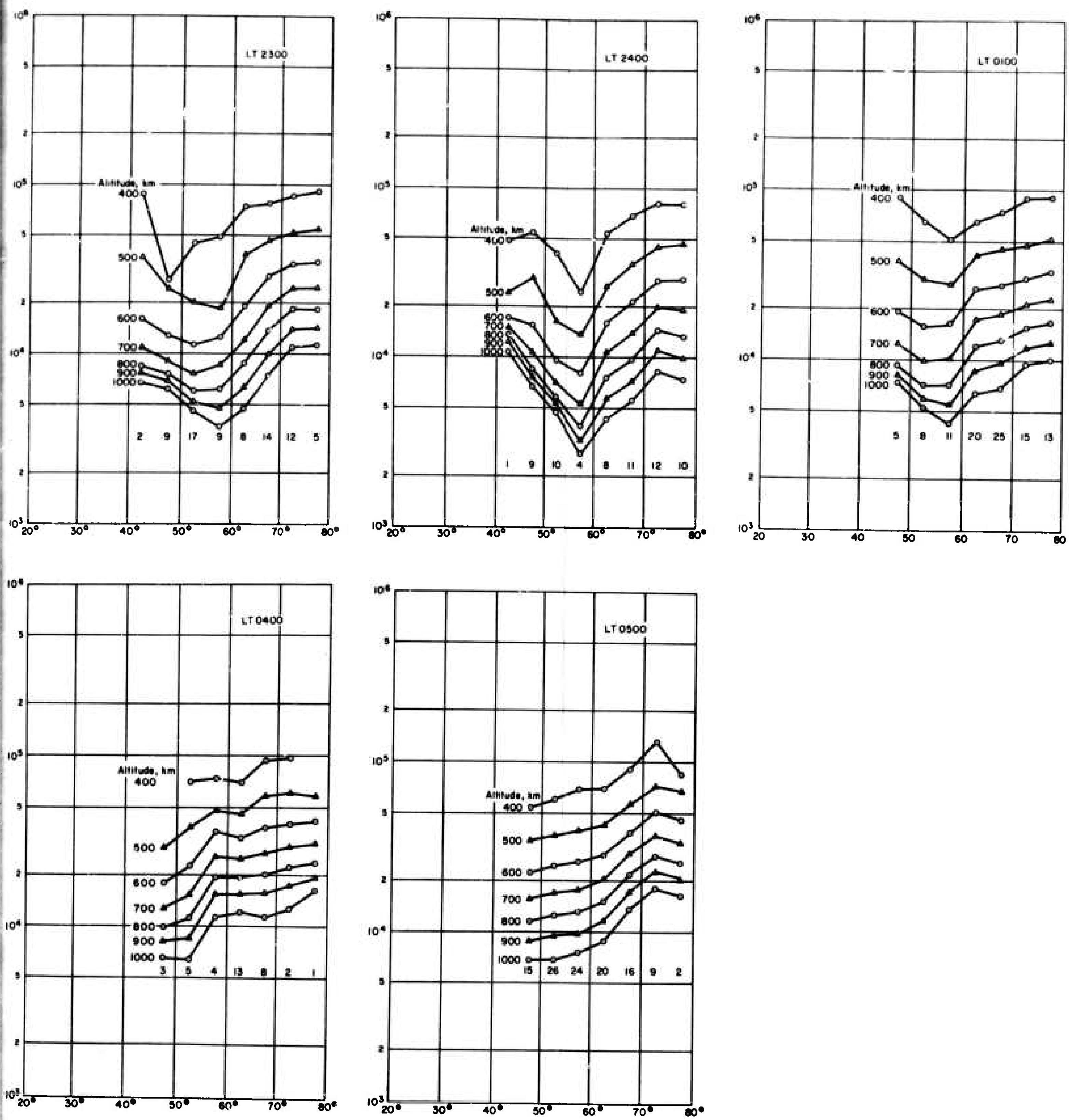
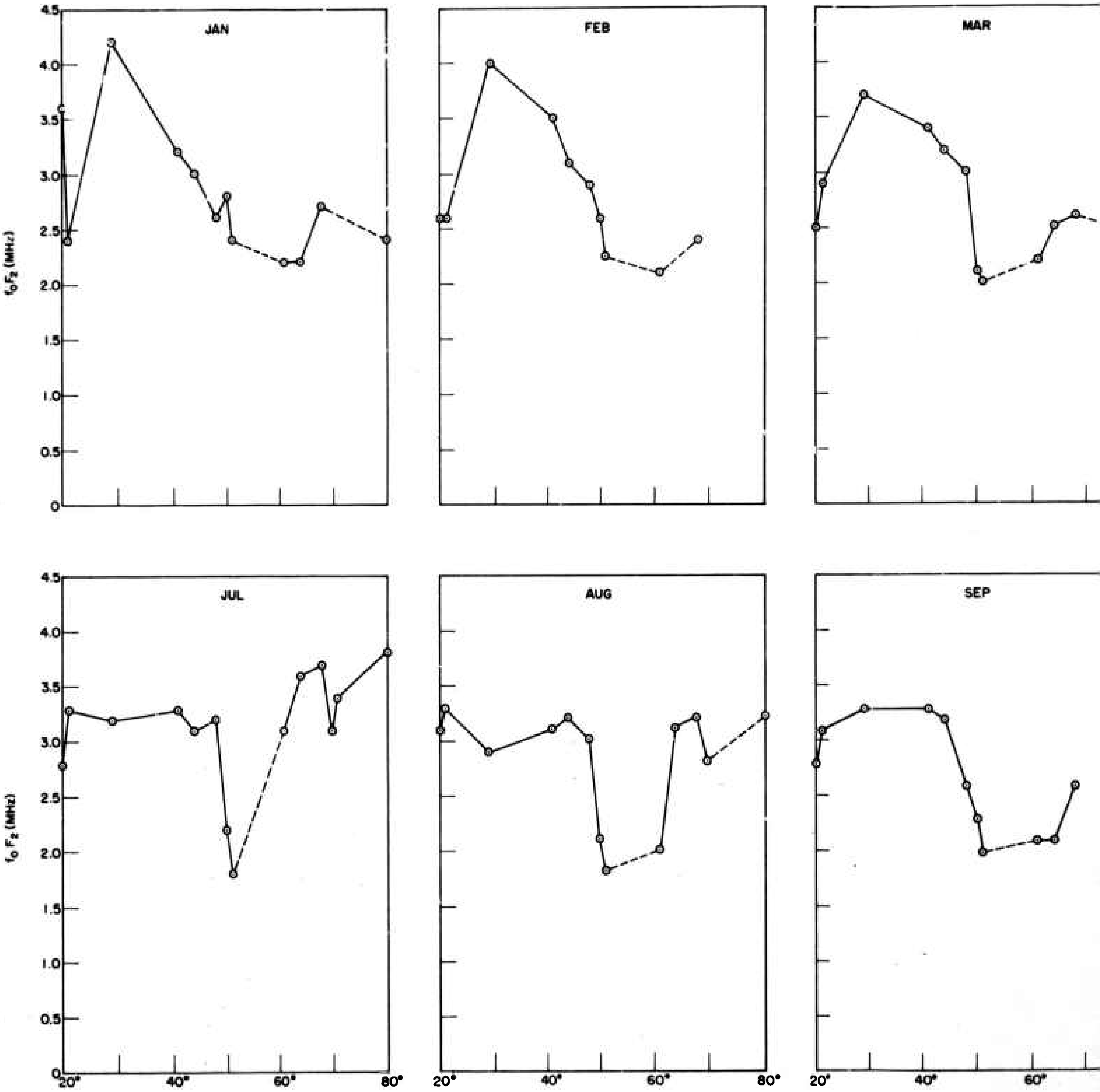


FIG. 11. DIURNAL ELECTRON DENSITY VARIATIONS FOR THE SUMMER OF 1963. The numbers under the data points on the plot are the number of measurements averaged for each point.


JAN
FEB
MAR
JUL
AUG
SEP
f_0F_2 (MHz)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
20°
40°
60°
80°

1

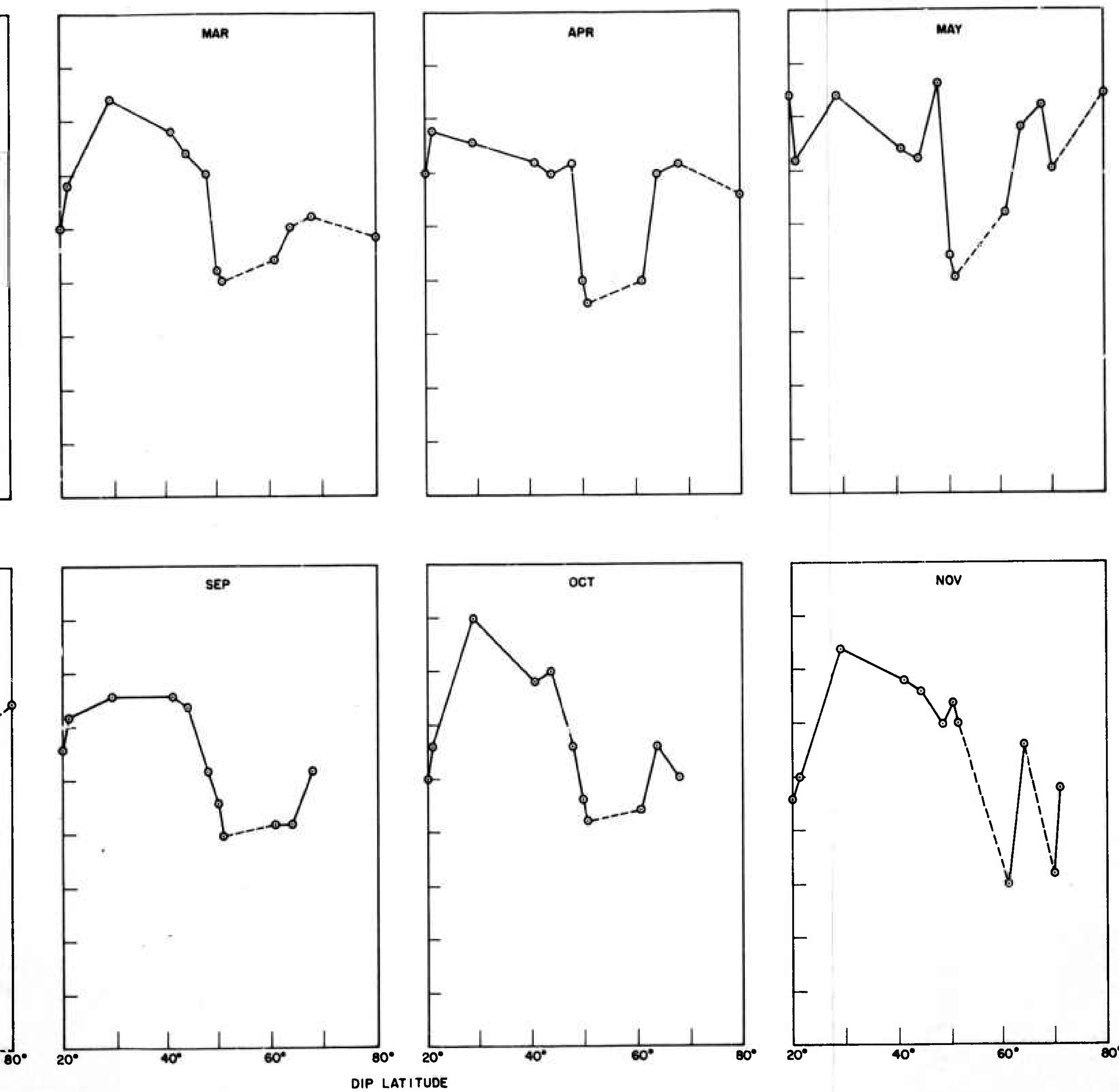


FIG. 12. SEASONAL
f_oF_2 IN 1954 FO

2

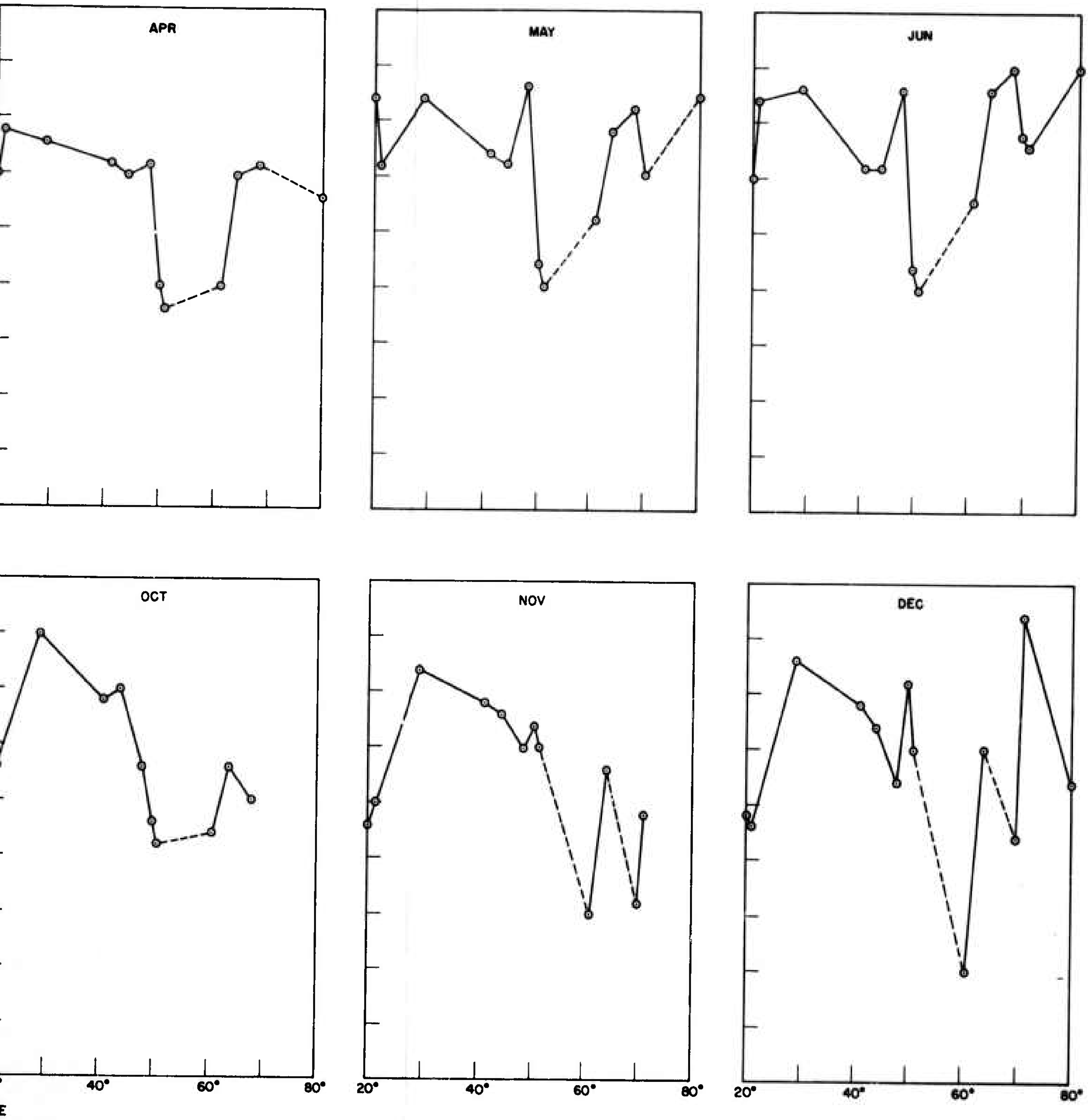


FIG. 12. SEASONAL VARIATIONS IN MONTHLY MEDIAN f_oF_2 IN 1954 FOR 0300 LOCAL TIME.

III. IMPLICATIONS ON EAST-WEST PROPAGATION IN THE U.S.

If the crinkle anomaly really exists in any but a sporadic form, the MUFs from, say, New York to San Francisco would be reduced by approximately a factor of 2 during periods of low sunspot numbers, summer months, and early morning hours, with less reduction when any of these conditions are not met. However, the MUFs from, say, Boston to Seattle or Miami to Los Angeles would not be affected. Thus, communication capabilities across the mid-U.S. would be seriously reduced during such periods, but the available evidence supporting a reproducible crinkle is small.

A minimum in electron density, which is sometimes observed, would cause deviations in radio rays which are reflected from the ionosphere near the edges of the crinkle. These deviations would cause azimuthal variations of the radio paths out of the great circle paths.

The data in Fig. 3 were graphed as electron density vs altitude at latitudes between 50° and 70° north latitude; a constant-shape lower ionosphere (Fig. 13) was added to each graph in such a way that the

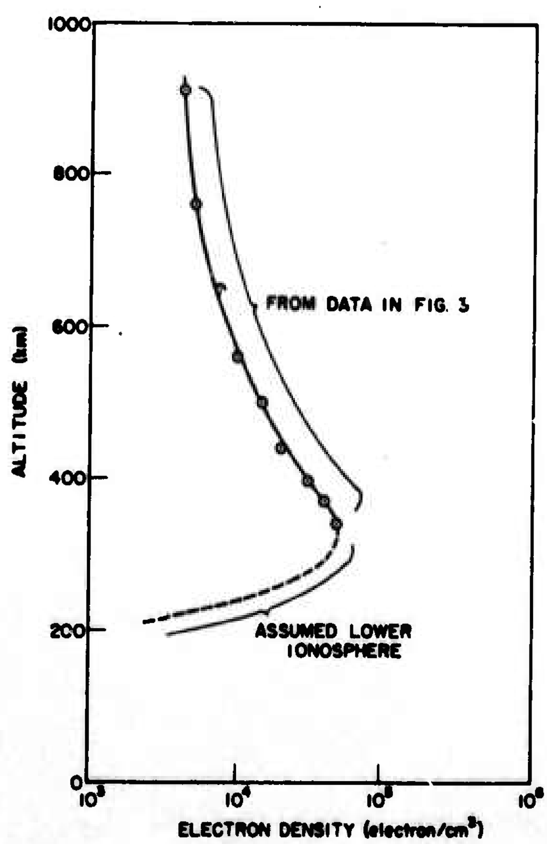
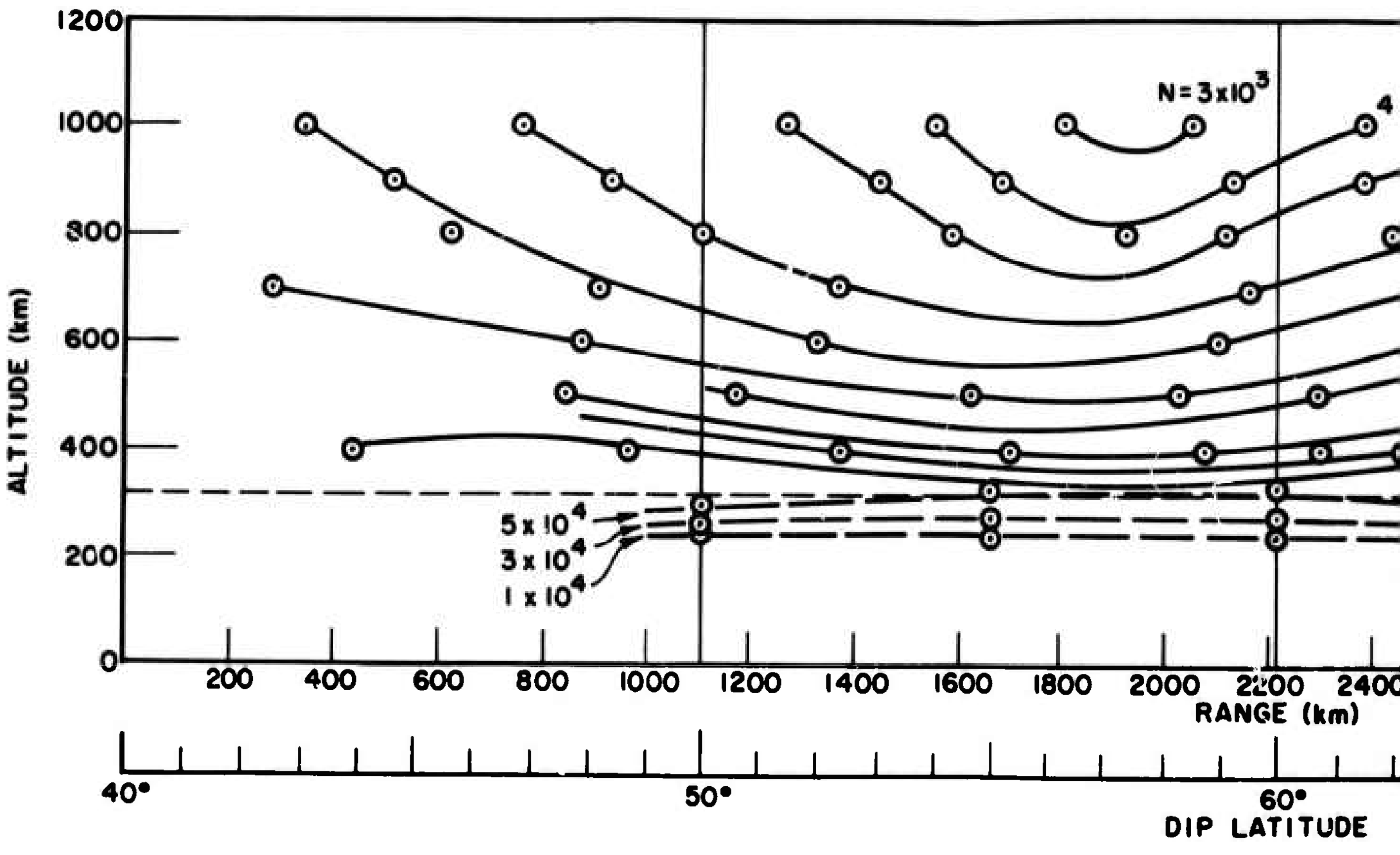


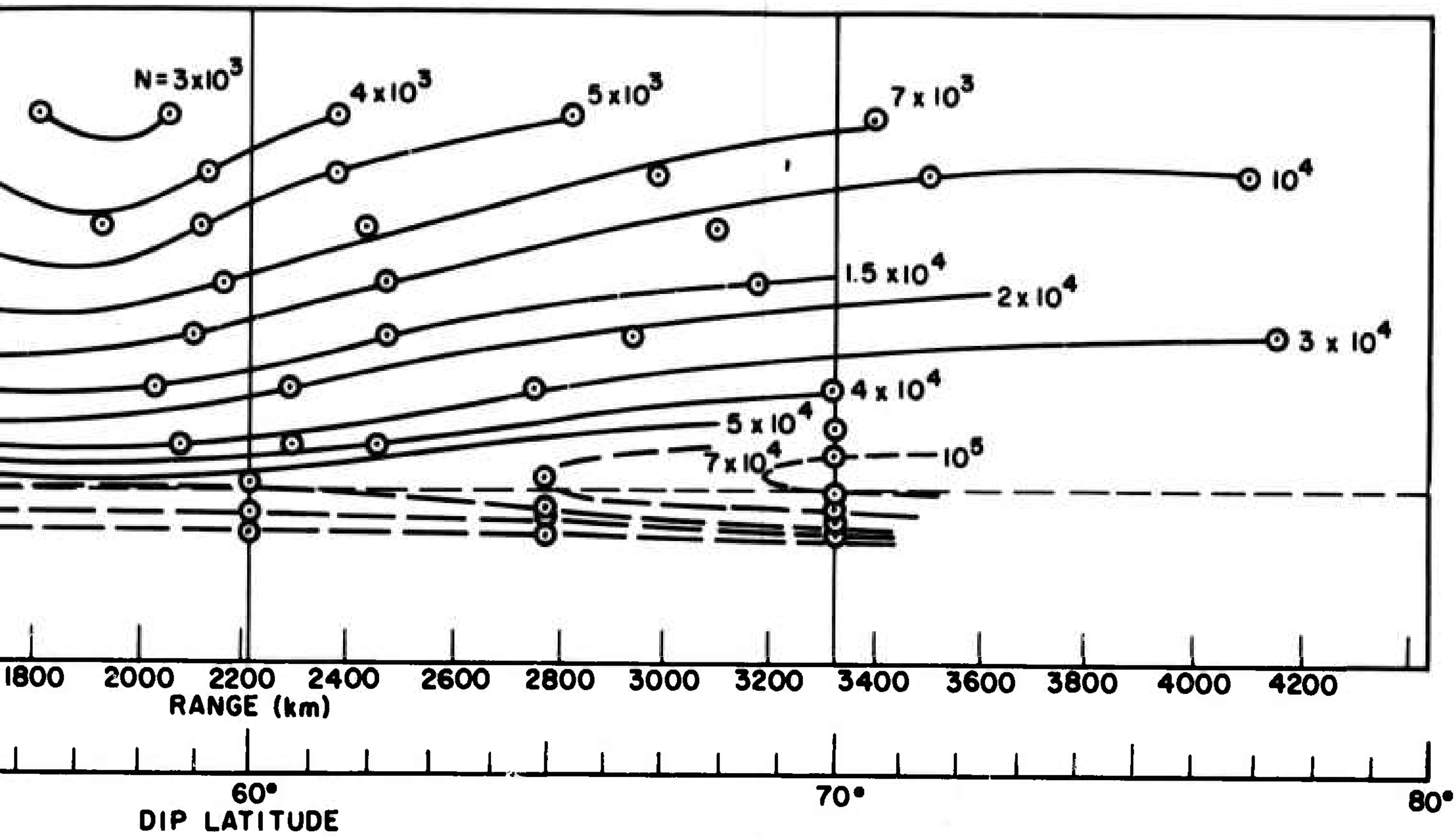
FIG. 13. IONOSPHERIC ELECTRON DENSITY PROFILE AT 55° NORTH DIP LATITUDE AT 2400 LOCAL TIME, SUMMER 1963.

maximum electron density occurred at the same altitude. Values scaled off of these graphs were then used to determine Fig. 14, which is a plot of constant electron density contours as seen in a north-south cross section of the ionosphere. In Ref. 14, similar plots are presented which do not show the crinkle, apparently because they represent high sunspot number data (these plots are reproduced here as Fig. 15).

From Fig. 14, slopes representing the ionospheric tilt at altitudes corresponding to frequencies at 0.8 of the MUF were determined; and by using the charts presented in Ref. 15, the maximum azimuthal deviation of a one-hop, 3000-km radio path was found to be about 120 km or 2.3° as referenced to the transmitter.


N=3x10^3
4
5x10^4
3x10^4
1x10^4
ALTITUDE (km)
0
200
400
600
800
1000
1200
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
RANGE (km)
40°
50°
60°
DIP LATITUDE

1



2

FIG. 14. IONOSPHERIC SECTION AT 2400 LOCAL TIME, SUMMER 1963.

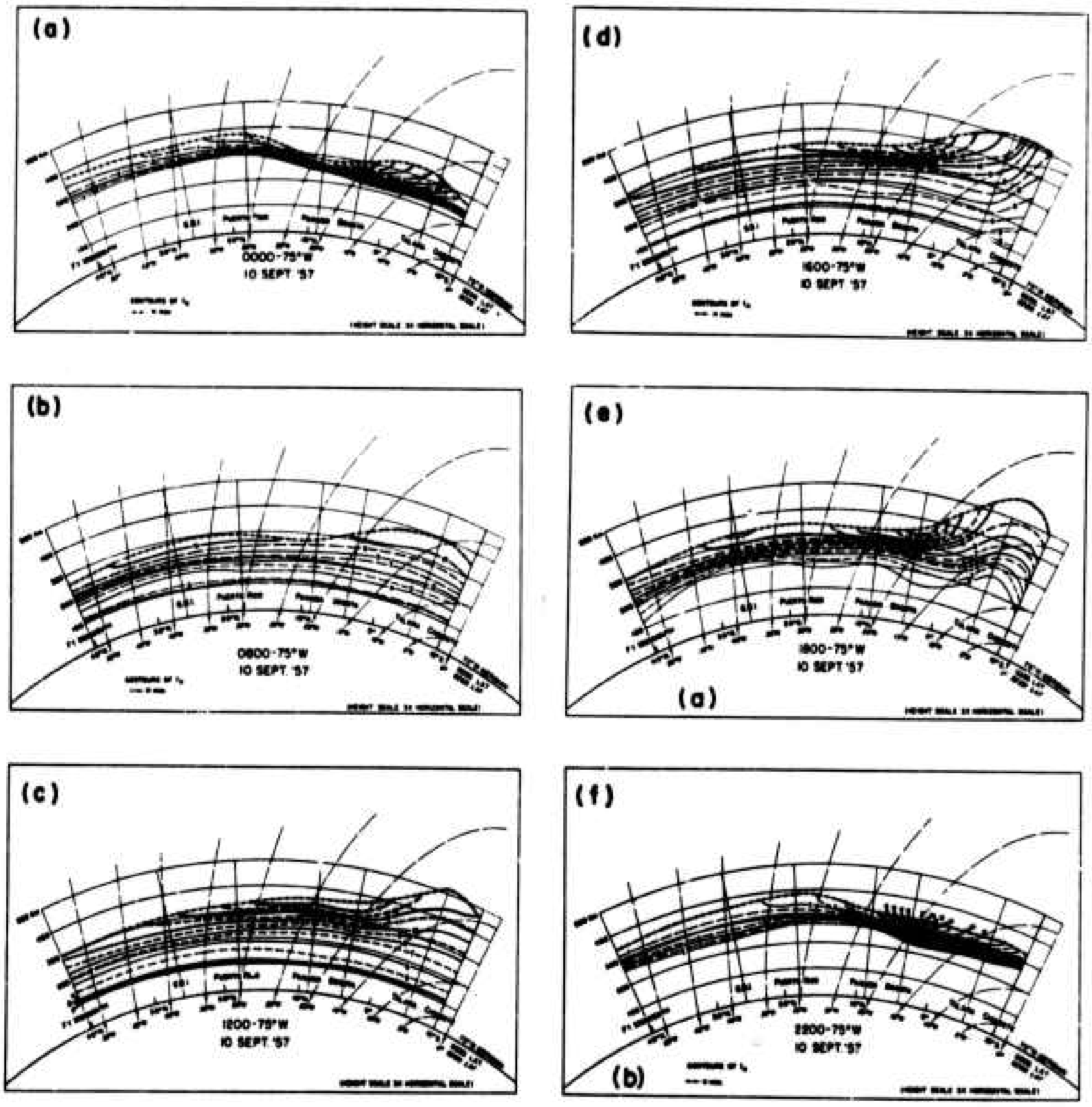


FIG. 15. EXAMPLES OF IONOSPHERIC SECTIONS THAT DO NOT SHOW ELECTRON DENSITY MINIMUMS. (From Ref. 14.)

IV. CONCLUSIONS

A trough of F-layer electron density lying in an east-west direction across the middle of the United States has been identified. Since it may have important implications in HF radio propagation across the U.S., the properties of such a "crinkle" have been investigated. The anomaly seems to have a width of about 10° latitude which is about five times as wide as Muldrew's troughs [Ref. 2] located at more northerly latitudes. It appears to be located about 55° north dip latitude and to remain at that latitude with variations of time and sunspot number. Such variations only produce differences in the depth of the minimum. This does not follow the pattern of Muldrew's troughs, which have a diurnal latitude variation.

The minimum of electron density which appears in many of the figures in this report seems to occur in the early morning hours, in the summer months, and at periods of low sunspot number. However, even during these periods of highest probability of occurrence, it is not observed in any of the surveyed single-pass data, but rather only in the averages of many observations (where it still is not reliably seen). Thus, much of the data scanned for this report did not show the minimum. Since highly selected data were used in preparing the figures, the reader should avoid the impression that there is considerable evidence to support a conclusion that the crinkle is a regular feature of the ionosphere.

It is our conclusion that, because of the infrequent occurrence and little understood nature of the trough, and the small lateral deviations it produces in east-west radio propagation, decisions on transmitter and receiver locations in the U.S. should not be affected by possible degradation in HF communications due to such an anomaly in F-layer electron density. However, if all other factors were the same, a more southerly location would decrease the probability that a perceptible degradation would occur.

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13. ABSTRACT

It has been suggested that recent satellite topside sounding data seems to show a trough or localized minimum of electron density lying latitudinally across the United States. The characteristics and implications of such an F-layer anomaly have been investigated by surveying and analyzing available topside and bottomside sounding information. A trough does appear in some of the data, and it appears to have diurnal, yearly, and sunspot cycle variations. However, even during these apparent periods of highest probability of occurrence, it is not observed in any of the surveyed single-pass data, but rather only in the average of many observations (where it still is not reliably seen). Thus the conclusion was reached that, although the existence of such an anomaly in F-layer electron density would have an effect on HF point-to-point communications MUFs, nevertheless, owing to its infrequent occurrence and little understood nature, the possible existence of the anomaly should not be used as a design consideration in the layout of actual or proposed HF communications circuits across the U.S.

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